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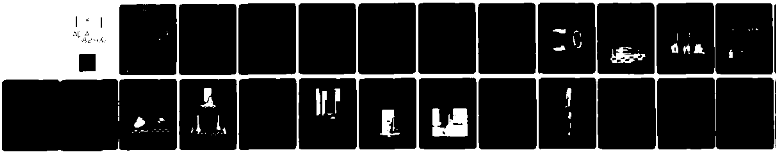

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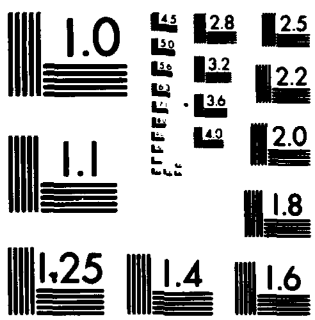

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DEVELOPMENT OF A LOW-COST FIELD FIX FOR THE RU-21H AIRCRAFT ANTENNA

I. E. Figge

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February 1980

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Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A low-cost field fix for the RU-21H (Guardrail) aircraft antenna was developed, tested, and installed on a fleet of RU-21H aircraft to prevent catastrophic failure of the antennas, which was occurring in the field between 500 and 1000 hours of operation. The fix, consisting of a glass reinforced injection molded Acetate Butyl Styrene (ABS) cuff, was installed using the existing bolt pattern on the flange of the antenna. It cost approximately $25 per antenna and could be installed in approximately 30 minutes, as compared to an existing two-piece fix with an estimated cost of $1300 per antenna and requiring approximately a five-week —

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downtime per aircraft. The cuff fix has been operational for approximately three years, and to date there are no known failures. Testing indicated that the cuff fix could be used to repair antennas with cracks up to 1 inch in length. During installation of the cuff, a second failure mode was observed on those antennas located near the engine nacelles. A longitudinal stiffener bonded along the length of the antenna was designed, evaluated, and installed, eliminating this problem.

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INTRODUCTION

The RU-21H (guardrail) aircraft uses 18 fiberglass antennas in the performance of its mission. It was discovered that after 500 to 1000 hours of field use, a large portion of the antennas were failing as the result of fatigue cracks in the vicinity of the leading- and trailing-edge flange radii. A two-piece (spanwise split at mid-chord) fiberglass cuff repair (Figure 1) was developed, under contract, subjected to limited fatigue testing, and was in the process of being installed on the fleet of RU-21H aircraft. This fix required that the antenna be removed from the aircraft, shipped to the contractor for installation of the cuff repair, shipped to another facility for antenna characteristic measurements, and then returned to the user for installation and calibration on the aircraft. This effort required approximately a five-week aircraft downtime at an estimated cost of about $1300 per antenna ($23,400 per aircraft).

To avoid the excessive downtime and cost of the contractor's fix, the Maintenance Directorate, U.S. Army Aviation Research and Development Command (AVRADCOM), St Louis, Missouri, requested that the Applied Technology Laboratory (ATL) assist in developing a low-cost field fix. Criteria established by AVRADCOM for the repair were as follows:

1. Application of the repair must be within the capabilities of an aircraft direct support maintenance facility, e.g., MOS 68G20,* with limited general support assistance permissible. The instructions for application of the repair and the attendant quality control criteria must be complete and fully detailed.

2. As a minimum, the repair must restore structural integrity of the antenna to a strength level at least equal to the original design; as a goal, it should provide improved resistance to failure.

3. The repair must be aerodynamically smooth.

4. Changes to the length of the antenna attachment screws, as well as the requirement for additional shims, spacers, or doublers as the result of application of the repair, must be delineated in the repair instructions.

This report presents the results of a failure mode investigation of the contractor's repair and covers the development, testing, and installation of the repair developed by the Applied Technology Laboratory.

*MOS 68G20 - Aircraft Structural Mechanic

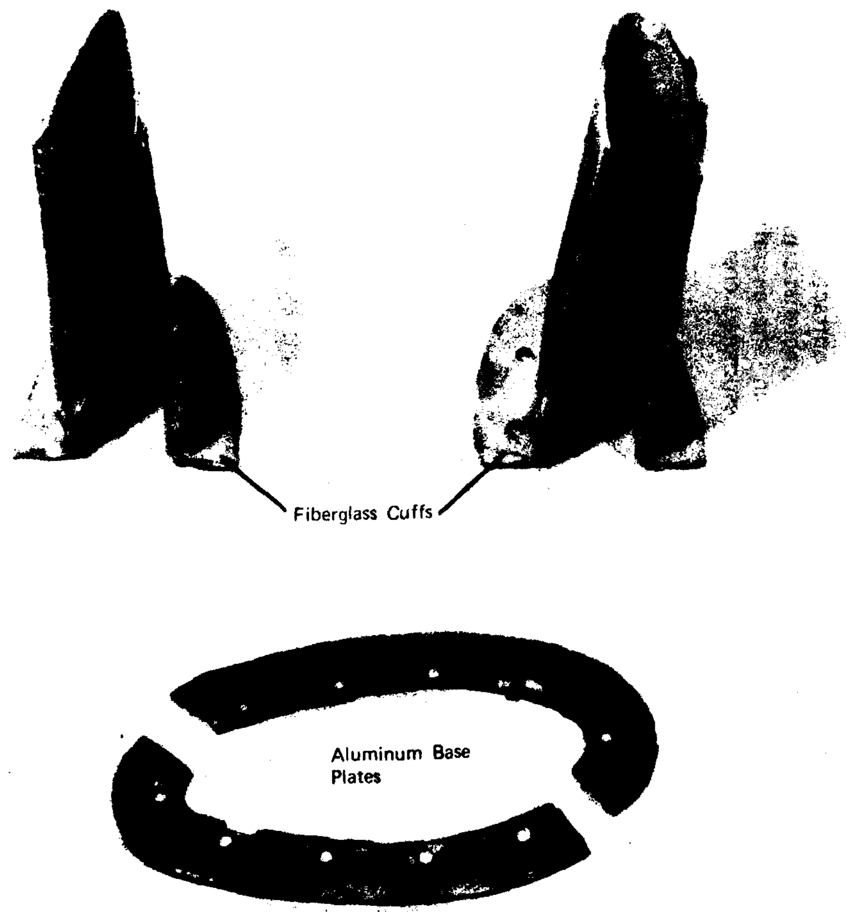


Figure 1. Contractor's antenna modification.

FAILURE MODE INVESTIGATION

Due to the limited number of antennas available for evaluation, various portions of the investigation were scheduled to obtain the maximum amount of information; as a result, some of the efforts were done out of sequence (the ATL fix was developed and evaluated prior to verification of the failure mode), and some of the efforts were not completed prior to proceeding with other efforts. However, for continuity of reporting, they are presented as continuous efforts.

VISUAL INSPECTION

Two cracked antennas with the contractor's fix installed (antennas 2 and 5) and one unused antenna were received for initial study. Information provided by the contractor indicated that the failures on antennas 2 and 5 were induced by a fore and aft (chordwise) motion of the antennas. In order to verify this statement, the fixes were removed for inspection of the failure area. During this inspection, it was found that the cuffs were ineffectively bonded to the mast. It appeared that the surfaces of the mast and the cuffs had not been properly prepared prior to bonding, and the dimensions of the cuffs were such that the halves butted together prior to the inner surface of the cuffs coming into contact with the mast. In antenna 2 there was an inadequate amount of adhesive; thus only about 15 percent of the area was actually bonded. The bonded area separated easily when a wedging force was applied with a putty knife. There was essentially no bond in antenna 5. Figure 2 shows the smooth, shiny inner surface of the cuff, which is indicative of a poor bond, or no bond.

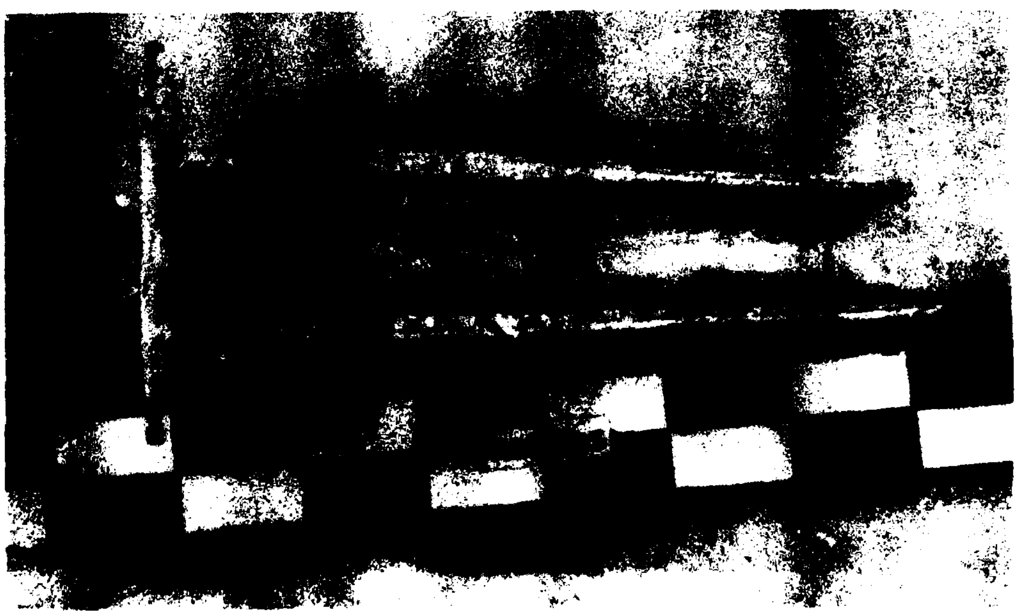


Figure 2. Contractor's cuff - removed from antenna.

SECTIONING

Upon sectioning of antenna 2, it was found that there was gross compaction of the fiberglass cloth in the mast/flange radii (see Figure 3), and that glass-filled resin was used to fair out the compacted area to its design dimensions. Excessive resin starvation in the structural fiberglass material was apparent in the flange radii area. Additional sectioning along the leading and trailing edges of the flange radii revealed a gross folding condition of the material to the extent that it functioned as a "hinge point" rather than a load-carrying structure (Figures 4(a) and 4(b)). This folding was also observed in antenna 5 (Figures 5(a) and 5(b)). Compaction/resin starvation of the material in the flange radii area on the sides of antenna 5 did not appear as excessive as that found in antenna 2.

These findings indicated that the failure was the direct cause of poor fabrication and design and that the fix (due to inadequate bonding/tolerances) would not prove to be an effective repair. Later testing by the U.S. Army Electronics R&D Command (ECOM) verified these findings.

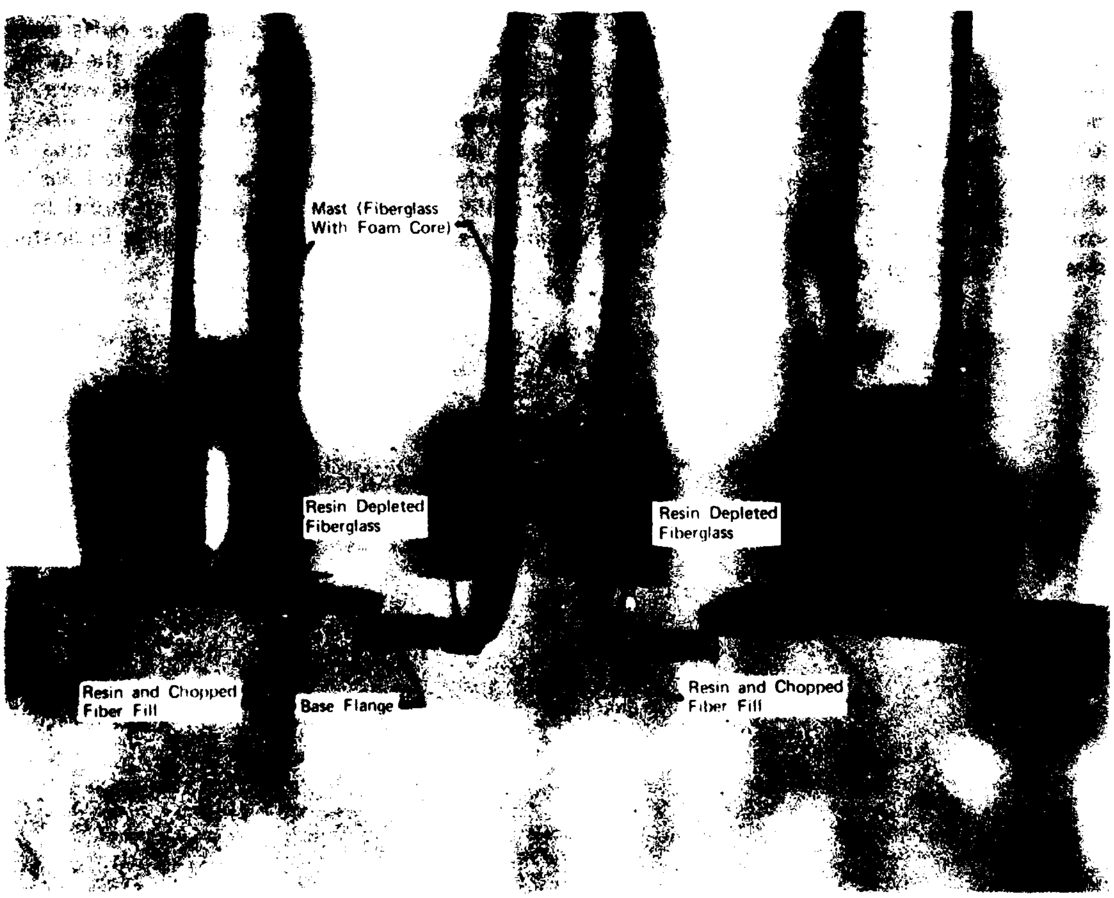
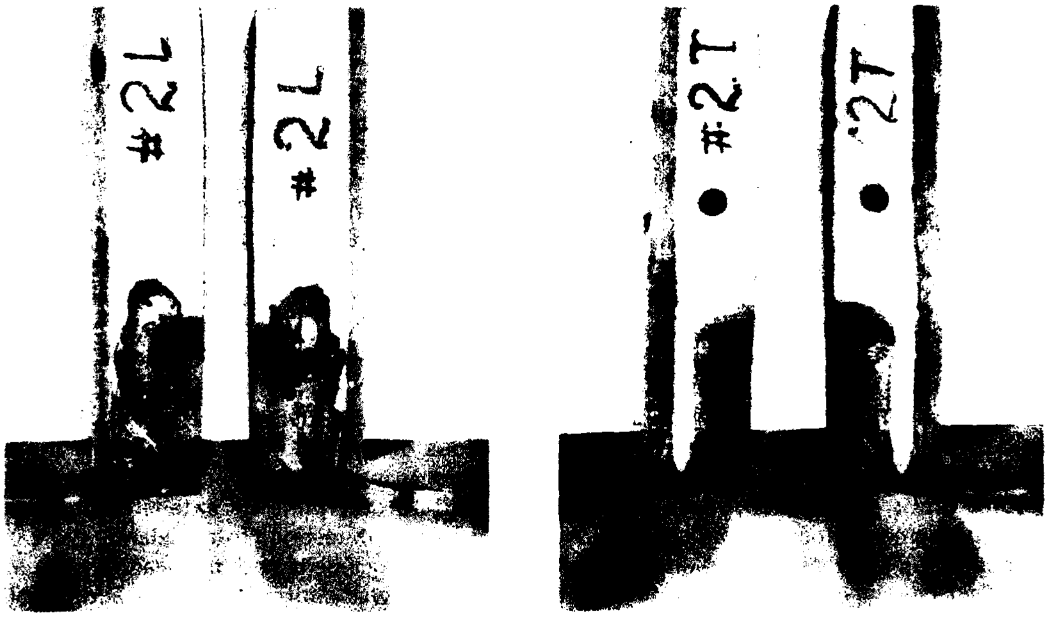
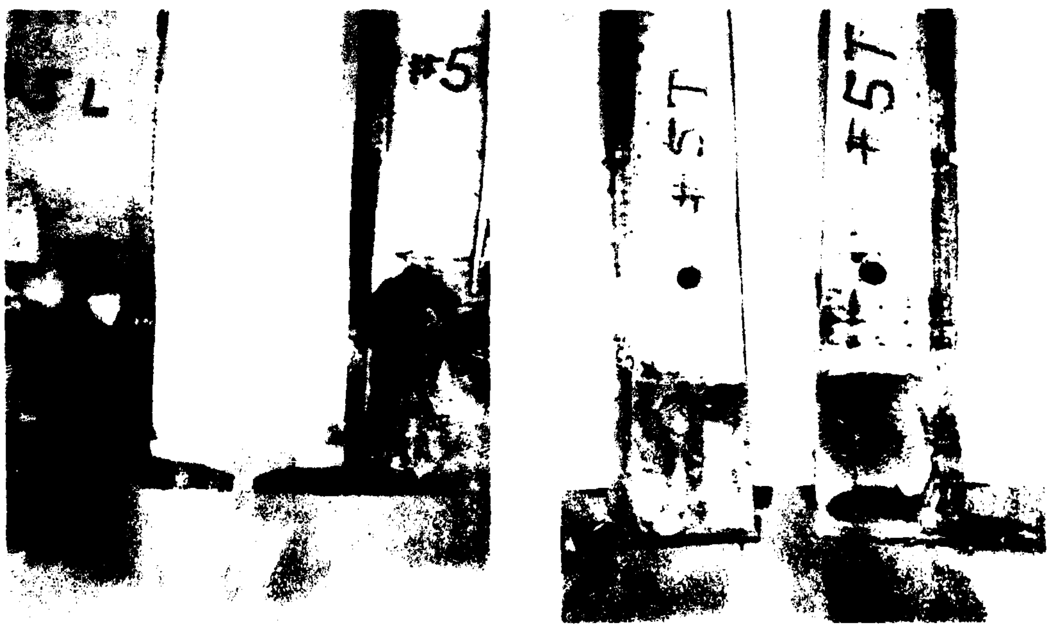


Figure 3. Existing antenna - cross sections.



a. Leading edge. b. Trailing edge.

Figure 4. Antenna 2 - cross sections.



a. Leading edge. b. Trailing edge.

Figure 5. Antenna 5 - cross sections.

TESTING

Antenna 5, with the contractor's fix removed, was tested at 14½ Hertz (first torsional resonance), 4-g table-base acceleration on an All-American horizontal shake table for 37 minutes without visible crack growth or change in resonant frequency (test sequence 4; Table 1). The antenna was then excited in the fore and aft mode, initially at 30 Hertz (first chordwise bending frequency), 10-g table-base acceleration (test sequence 5). Almost immediately both the frequency and the acceleration began to drop off appreciably. The test equipment was adjusted in order to maintain the frequency at resonance and to maintain the base acceleration in the neighborhood of 10 g. After 1 minute, the test was stopped and the crack examined to determine if crack propagation had occurred. No extension of the existing crack was visible; however, considerable heat had been generated in the crack areas, indicating appreciable working. Testing was continued for another minute, at which time the test was again stopped and the crack examined. Obvious delamination of the material in the vicinity of the initial leading- and trailing-edge cracks was evident. There also appeared to be some crack propagation; however, it was difficult to determine its extent because of the high degree of local delamination. After 4 minutes of testing, total delamination in the flange radii completely around the antenna base was evident and the leading-edge crack had clearly extended an additional inch. Testing was continued for an additional 4 minutes, during which time the resonant frequency dropped to 16 Hertz and base acceleration dropped to 6 g. Complete cracking of the outer ply of material on one side of the antenna was evident and the stiffness of the blade was obviously reduced. By applying slight hand pressure to the upper portion of the antenna, it appeared that the mast had separated from the flange in the underlying layers of fabric. The antenna was not considered to be flightworthy at this point.

These tests verified that the torsional excitation was not critical, whereas the fore and aft mode did induce cracks similar to those experienced in the field.

TABLE 1. TEST RESULTS

Configuration	Contractor Spec No.	Test Sequence	Test Mode	Frequency (Hz)	G Table Base	Temperature (°F)[a] Without Cooling	With Cooling[b]	Test Time (min.)	Cycles	Remarks
Failure Mode Investigation										
Basic antenna	5	4	Torsion	14.5	4	-	-	37	32,190	No crack propagation.
Basic antenna	5	5	Fore and aft	30-16[c]	10-6[c]	-	-	8	11,040	Total delamination around flange radii. Antenna considered non-flightworthy.
Testing ATL Repair										
Phenolic aft cuff installed	5	1	Fore and aft	41	10	155	97	270	664,200	No crack propagation.
Phenolic aft cuff installed	5	2	Lateral	15	1[d]	68	-	180	162,200	No crack propagation.
Phenolic aft cuff installed	5	3	Torsion	11	4[e]	68	-	180	118,800	No crack propagation.
Phenolic aft cuff installed (Antenna failed in test sequence 5)	5	6	Fore and aft	33.5-32	10	127	-	180	353,700	Specimen considered failed prior to start of test. Fix appeared totally effective in restoring operational capability.
Phenolic aft cuff installed	Unused	7	Fore and aft	53-52	10	105	-	120	378,000	Some subsurface working noted in LE flange radii after 40 min; working stabilized.

TABLE 1. Concluded.

Configuration	Contractor Spec No.	Test Sequence	Test Mode	Frequency (Hz)	G Table Base	Temperature (^{o}F)[a] Without Cooling	Temperature (^{o}F)[a] With Cooling[b]	Test Time (min.)	Cycles	Remarks
Phenolic aft cuff installed; 15 in.-lb on thru-the-mast bolt simulating nonmetallic bolt	Unused	8	Fore and aft	54	10	121	-	38	123,120	No crack propagation. Working in LE flange radii evident.
Phenolic aft cuff installed; thru-the-mast bolt removed	Unused	9	Fore and aft	59	10	109	-	210	743,400	No crack propagation. Working in LE flange radii evident.
Phenolic aft cuff installed; two tapered fiberglass pins	Unused	10	Fore and aft	53	10	-	93.2	1680	5,340,000	No crack propagation. No change *in frequency*.
Second Mode Resonance Investigation (-4 Antenna)										
Phenolic aft cuff installed	-	11	Lateral	62	-	-	-	2	7,440	Cuff split; antenna failed in upper portion similar to those in field.
Phenolic aft cuff and hat section stiffiners	-	12	Lateral	111 (Note: 62 Hz without stiffeners)	-	-	-	15	99,900	Antenna mounted horizontally. Significant reduction in tip deflection.

(a) Measured in area of maximum relative motion between mast and cuff.
(b) 14-inch-diameter fan placed approximately 2 feet from specimen.
(c) Frequency and base acceleration continually dropped off during test.
(d) Machine limited.
(e) Adjusted to limit leading edge deflection (torsional) to ±.75 inch.

ATL REPAIR

DESIGN

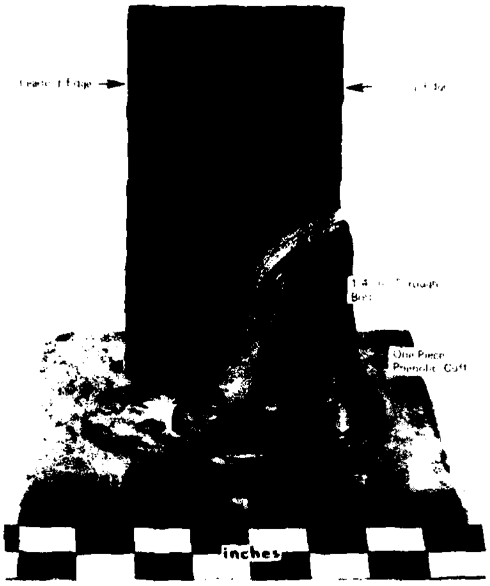
The design philosophy of the ATL fix was predicated on the assumption that the fore and aft motion, as indicated by the contractor's report, was critical. As in the contractor's repair, the ATL fix included local stiffening of the flange radii. In order to meet the basic design criteria established by AVRADCOM, the fix was to utilize the existing bolt pattern on the flange of the antenna, and it was to be designed such that it would not be dependent upon adhesive bonding to transfer the load.

After several iterations, a design evolved which consisted of a U-shaped phenolic cuff mated with the trailing-edge section of the mast and secured by using the aft seven flange bolt pattern (Figure 6). A 1/4-inch steel bolt (torqued to 100 in.-lb) through the mast of the antenna was initially used to react the bending moments (Figures 7(a) through 7(c)). Weight of the cuff was 136.2 grams. A thin layer of silicone rubber (cured in place for 16 hours) was used between the trailing-edge cuff and the mast to ensure a positive fit.

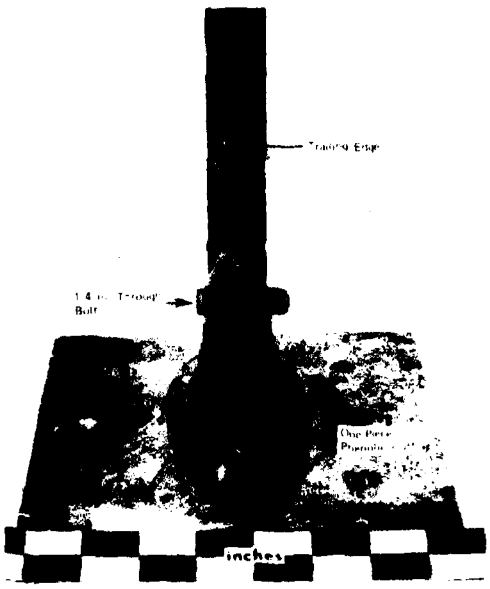
a. Top view.

b. Bottom view.

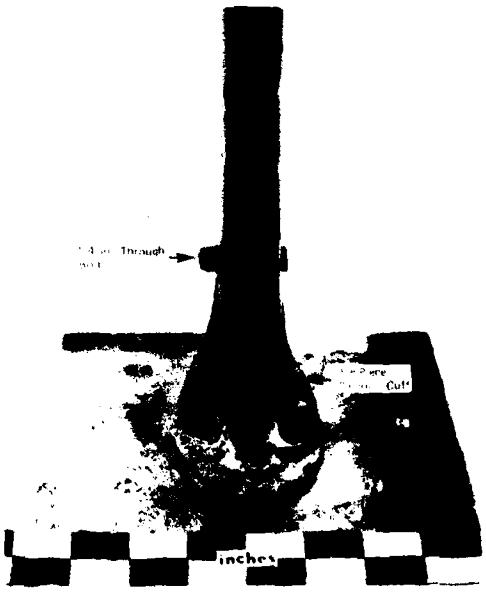
Figure 6. One-piece phenolic cuff.



a. Side view.



b. Rear view.



c. Front view.

Figure 7. Test configuration.

TESTING

Unused Antenna

The ATL fix was installed on antenna 5 and tested on the horizontal shake table in the fore and aft mode with a peak table acceleration of 10 g at the first mode chordwise resonant frequency of 41 cps (test sequence 1; see Table 1). A thermocouple was mounted on the flange of the antenna to measure changes in temperature, indicating additional damage. The temperature stabilized at 155°F without cooling and 97°F with cooling (which was supplied by a 14-inch-diameter fan mounted 24 inches away from the antenna). The ambient temperature was approximately 72°F. The test was terminated after 4½ hours without any evidence of additional crack growth in the flange radii.

The specimen was then rotated 90 degrees and testing (test sequence 2) was resumed to excite first mode lateral bending (flapwise) at 15 Hertz and approximately 1-g base acceleration (machine limited). The lateral mode test was terminated after 3 hours with no crack growth observed.

The antenna was then excited for 3 hours in torsion at 11 Hertz, 4-g base acceleration (test sequence 3) using a pendulim clamped to the upper end of the mast/trim tab (Figure 8). The base acceleration was adjusted to 4 g to obtain leading-edge tip deflection of ±.75 inch. As before, no crack growth or change in resonant frequency was observed in the torsional mode. Based on the results of these tests, the design was considered to be acceptable.

A 3-hour test (test sequence 6) was then conducted on antenna 5, which was considered completely failed due to excitation in test sequence 5, to qualitatively determine the extent of damage repairable by the fix. The frequency at the beginning of the test was 33.5 Hertz (fore and aft mode/10-g base acceleration), compared to 16 Hertz without the cuff. This increase in frequency is indicative of a factor of approximately 4 increase in fore and aft bending stiffness due to the addition of the cuff. After approximately 1 hour of testing, the frequency stabilized at 32 Hertz. Temperature of the cuff/antenna interface stabilized at approximately 127°F. Results of this test indicate the ability of the aft cuff to restore the structural integrity of antennas with excessive damage.

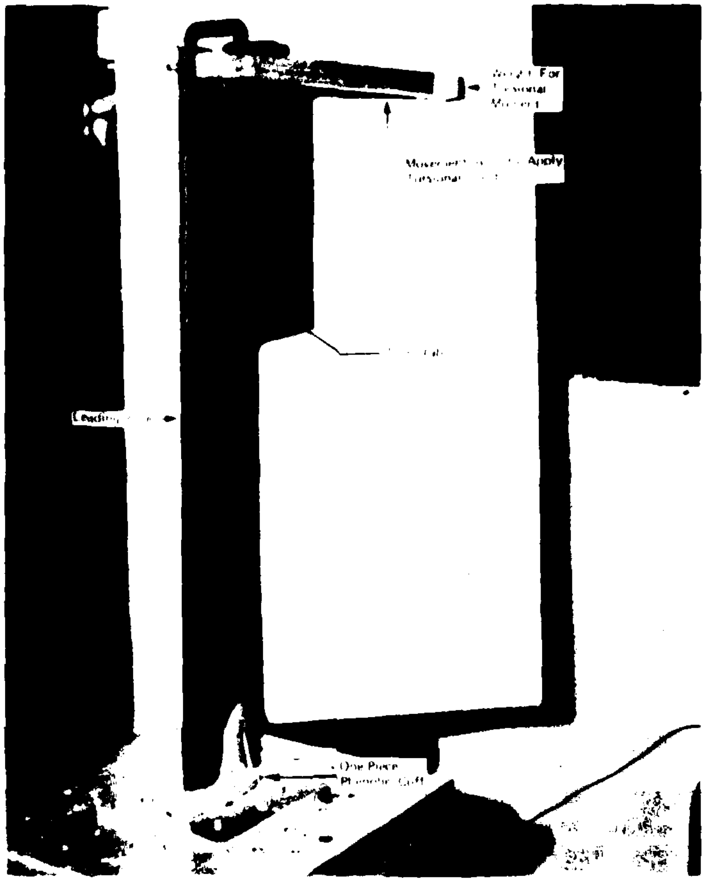


Figure 8. Torsional test configuration.

Unused Antenna

Tests were conducted to determine if the fix was capable of preventing cracks from forming in an unused antenna (test sequence 7). Upon initiation of the test (53 Hertz in the fore and aft mode at 10-g base acceleration), cracks were visible in the protective coating in the area of the flange. Removal of the coating, however, revealed that there was no cracking in the basic antenna structure. The resonant frequency stabilized at 52 Hertz after approximately 1/2 hour of testing. After 40 minutes of testing, there appeared to be a crack between the antenna material and the fill material in the flange radii. Some working in the area of the folded material on the leading edge was visually evident (observed with a strobe light) while running. This working could be expected due to the "hinge effect" in that area. The test was terminated after 2 hours with the temperature stabilized at 105°F. The extent of working appeared to remain stable and only slight heat buildup in the leading-edge folded material area was evident. Based on the results of this test, it was assumed that the fix was capable of preventing failures in unused antennas.

Additional tests (test sequences 8 and 9) were conducted on the unused antenna by applying 15 in.-lb (vice 100 in.-lb) of torque to the through-the-mast bolt to simulate the clamping force achievable with a nonmetallic (nylon) bolt and with the through-the-mast bolt removed completely. In both cases, subsurface working in the leading-edge flange radii was evident. The extent of the working appeared stable throughout the test. Testing with the through-the-mast bolt removed was terminated after 3½ hours with no evidence of crack propagation.

Based on the test results, it appeared that the through-the-mast metallic bolt was not critical in the functioning of the cuff. It was replaced by two tapered fiberglass pins positioned as shown in Figure 9. The tapered fiberglass pins, fabricated from unidirectional fiberglass rods, were coated with silicone rubber and installed with a torquing device designed to apply axial force to the pin. A 50-in.-lb torque was used to install the pins. The antenna was then reinstalled on the test equipment and tested at the first mode fore and aft bending resonant frequency for 28 hours (test sequence 10). There was no evidence of crack growth in the leading-edge flange radii, and the resonant frequency remained constant. There was no buildup of heat in the region of the cuff/antenna interface and no evidence of working in the tapered pin bearing areas. Test results were more than sufficient to establish the effectiveness of the revised through-the-mast nonmetallic attachment technique.

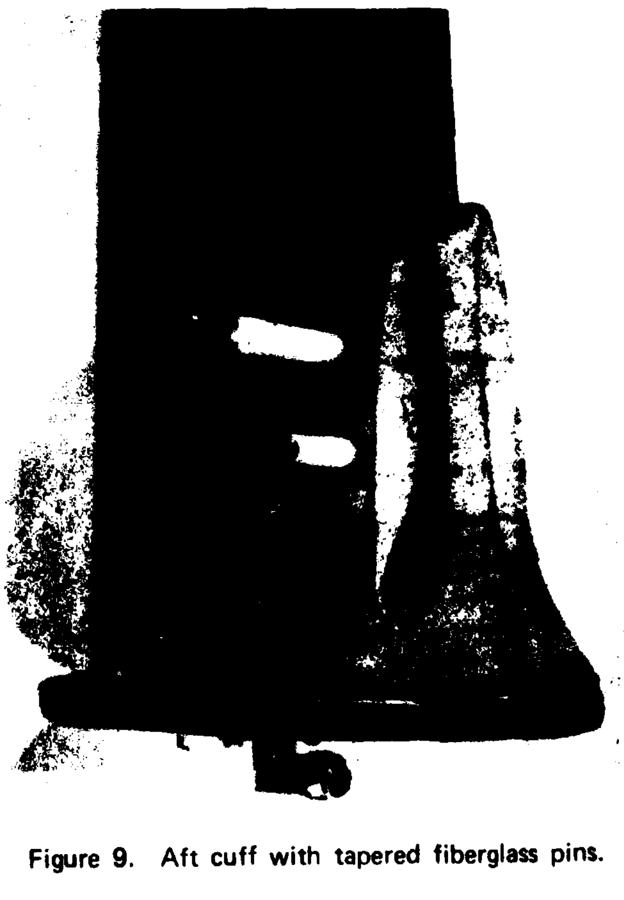


Figure 9. Aft cuff with tapered fiberglass pins.

Effect of Fix on Antenna Radio Characteristics

Tests were conducted to ascertain whether the fix had any effect on the antenna radio characteristics. An 80-inch by 80-inch aluminum foil ground plane was fabricated on a plywood base and the antenna was placed in its center as shown in Figure 10. Baseline measurements were +17 phase angle and 88 ohms impedance at 100 MHz. Initial measurements using a radio frequency vector impedance meter were made with and without 1/4-inch steel bolts taped to the antenna to determine any changes in the phase angle and the impedance. No change could be detected due to the addition of the horizontal/vertical and vertical orientation of the 1/4-inch bolts. Antenna characteristic measurements were made with the cuff installed with and without the through-the-mast bolt. There was no effect on either the phase angle or the impedance as a result of inserting the bolt through the mast. The antenna specifications permit a range of phase angle from +3 degrees to +18 degrees and impedance from 85 to 100 ohms at 100 MHz. These results indicated that the recommended fix could be installed without affecting the antenna radio characteristics.

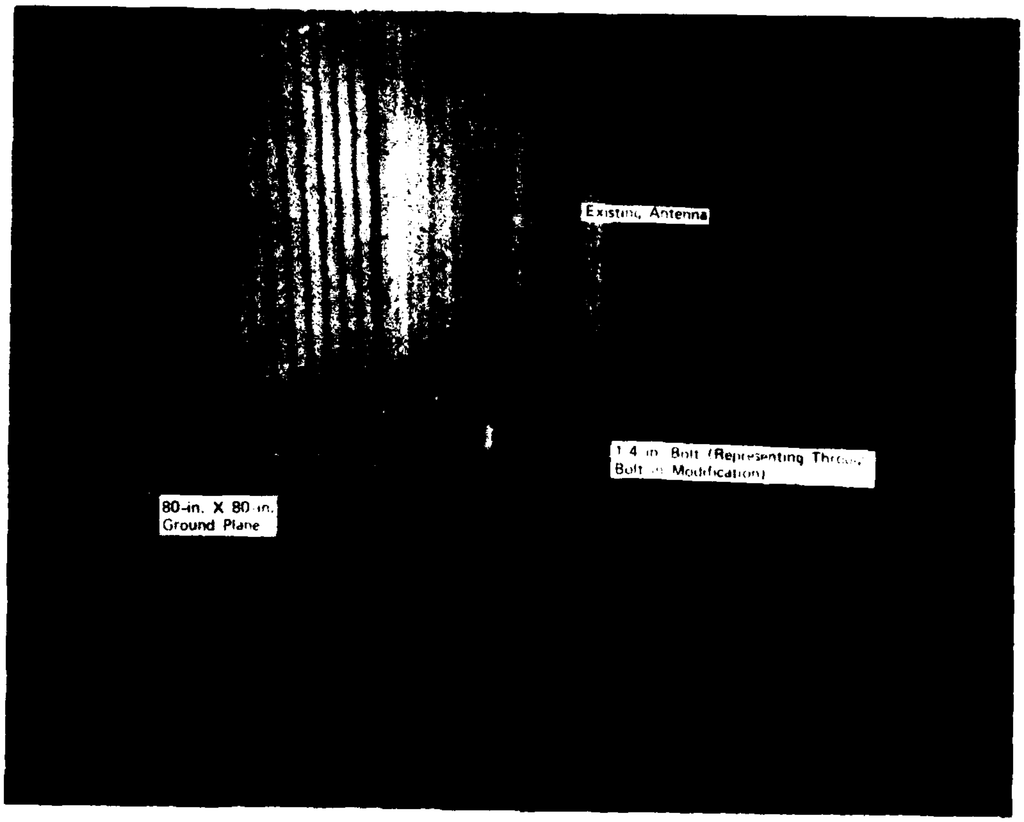


Figure 10. Existing antenna - electronic characteristics test.

FIELD INSTALLATION

Based on the success of the testing, ATL fabricated and installed one set of cuffs on an operating aircraft. During installation it was discovered that ground run-up of the aircraft produced extremely severe second and third mode lateral bending (peak-to-peak tip deflection greater than 4 inches) for the two 10-110621-4 antennas located on the underside of the wing in the area of the engine nacelles. The ground crews also indicated that the failure rate for these two antennas was by far greater than for those at other locations, being much less than the 500 to 1000 hours previously alluded to. In fact, one of the lower 10-110621-4 antennas, with the contractor's fix installed, had failed in the upper portion rather than in the base after only 3 hours of aircraft operation. This failure mode had also been observed on antennas without the contractor's fix. Based on on-site testing, it was apparent that the severe problems being experienced with the two antennas located under the wing near the nacelles were propeller vortex/ground proximity related.

Based on this new information, additional laboratory testing was conducted on an in-service failed 10-110621-4 antenna (lower wing-nacelle location) which indicated that the aft cuff alone was relatively ineffective in preventing damage in the upper portion of the -4 antennas under the severe lateral loading conditions being experienced during ground run-up of the aircraft. Under lateral second-mode bending tests (test sequence 11), the cuff split within a short period of time (approximately 2 minutes) and the antenna itself failed in its upper portion similar to that previously experienced in the field. Two approaches were investigated to alleviate this problem: (1) installation of nonmetallic guy wires and (2) reinforcing composite strips bonded the length of the antenna to substantially increase its overall lateral bending stiffness.

Although the guy wires successfully reduced the tip deflectons, the problems associated with obtaining nonmetallic wire, turn buckles, etc., and the potential field maintenance difficulties made this approach impractical. Therefore, the reinforcing strip approach was pursued. Hat stiffeners of fiberglass cloth (9 plys, 143 style S-glass cloth/epoxy resin) were fabricated and bonded (both sides) to the length of the antenna aft of the deicer (Figures 11 and 12). Laboratory testing in a 10-kip MTS fatigue machine with the specimen cantilevered horizontally indicated that the second mode lateral bending frequency increased from approximately 62 Hertz without the stiffeners to 111 Hertz with the stiffeners. The specimen was tested for 15 minutes without any evidence of failure.

Based on the success of the laboratory testing, a modified antenna (cuff plus stiffener) was installed on the underside of the wing in the nacelle area (critical lateral bending location). Ground run indicated that the tip deflection was approximately 3/4 inch peak to peak as compared to over 4 inches for the unstiffened antenna. The stiffeners and cuffs were installed on all 10-110621-4 antennas (underside-nacelle location), and cuffs without stiffeners were installed on the remaining 16 antennas, using the installation procedure described in Appendix A.

Figure 11. Fiberglass hat stiffeners and cuff prior to installation.

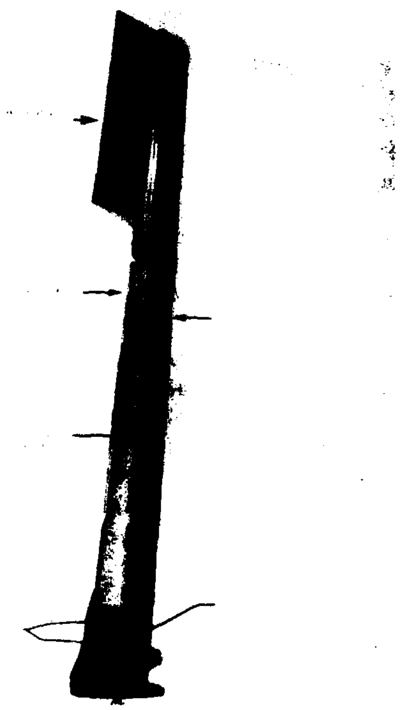


Figure 12. RU-21H antenna with ATL repair installed (cuff and hat stiffener).

CONCLUDING REMARKS

Based on the success of this effort, a sufficient number of repair sets were fabricated to repair the remaining aircraft in the field. Injection-molded, fiber-reinforced ABS material was used to duplicate the cuff design.

The cost of these cuffs is $11.25 each and the cost of the tapered fiberglass pins is $6.50. The ATL-developed cuffs and -4 stiffeners were installed on the remaining aircraft in the field. The cuff fix has been operational for approximately three years, and to date there have been no known failures of the antennas.

It is concluded that failure of the RU-21H antenna was the result of inadequate manufacturing techniques which produced severe folding in the material in the leading- and trailing-edge flange radii, rendering the antenna effectively "failed" prior to installation. Use of antenna designs that employ integral mast/flange constructions will most likely produce problems due to the geometric constraints associated with producing the flange. It is recommended that either alternate designs be considered or additional reinforcement be used in the flange area if an integral mast/flange construction is utilized.

APPENDIX A
INSTALLATION PROCEDURE AND MATERIAL REQUIREMENTS

1. Clean all foreign matter from base of mast to a height of 6 inches using MEK (unnecessary to remove paint from the antenna). Caution: Do not spill on aircraft, as MEK will soften paint.

2. Place template on rear bottom (trailing edge) corner of antenna deicer boot and trace cut line radius.

3. Repeat step 2 on reverse side corner of antenna deicer boot.

4. Remove excess boot corner from both sides and clean bonding cement from mast in area where boot corner was removed, using MEK and 280/320 wet or dry emery paper. Caution: Do not allow excess MEK to penetrate under deicer boot, as this solvent will soften cement and weaken deicer boot installation.

5. Remove rear seven bolts from mast base (one at trailing edge, three on each side of antenna).

6. Coat inside and bottom of phenolic cuff and radius of mast base where cuff will attach with a 1/8-inch-minimum layer of RTV-103 *Silicone Adhesive (black)* FSN 8040-00-828-7385.

7. Position cuff on rear of mast base and fasten in place with seven AN-3 bolts, which are 1/2 inch longer than those removed, and AN-960 washers.

8. Tighten bolts to torque values recommended in basic antenna installation procedure.

9. Drill through predrilled pilot holes on side cuff of modification bracket with a 1/4-inch drill.

10. Ream top hole from left with a No. 5 3-inch H.S. steel taper reamer to end of reamer flutes.

11. Repeat step 10, reaming bottom hole from right.

12. Fill holes with RTV-103 silicone adhesive and insert fiberglass taper pins.

13. Install taper pin torquing tool (provided in kit) on taper pins and torque to 50 inch-lb. Remcve excess RTV.

14. Cut excess taper pin material off with a 32-tooth hacksaw blade going completely around pin before complete cut off. File with a 2d cut flat file. Seal ends of taper pins with thin coat of anti-static black paint or RTV-103 silicone adhesive.

15. Fill counter-bores, and leading edge of antenna at cuff base, with a thin layer of RTV-103 silicone adhesive and fair cuff contour using 1-inch putty knife. After air curing, a second coat of RTV may be required to obtain smooth surface.

Materials and Tool List

Tools

Caulking gun, FSN 5120-00-679-5655
Metal scriber
Razor blade
1/4-in. H.S. drill bit
1/4-in. drill motor
1-in. putty knife
1 No. 5 reamer (taper)
1/4-in.-drive 75 in.-lb torque wrench
Taper pin torquing tool
1/2-in. x 1/4-in.-drive socket
4-in. x 1/4-in.-drive extension
3/8-in. x 1/4-in.-drive extension
1/4-in.-drive ratchet
Blade, hacksaw, 32T
2d cut flat file

Materials

RTV-103 silicone adhesive, FSN 8040-00-828-7385
AN-3 bolts
Fiberglass taper rod

Modification Kit

Reinforcing phenolic cuff
Deicer boot trimming radius
Template
Bolt, aircraft, HEX head 10-32

AN 3-24, FSN 5306-00-144-3661 - 16 ea
AN 3-26, FSN 5306-00-144-3663 - 24 ea
AN 3-30, FSN 5306-00-144-3665 - 40 ea
AN 3-31, FSN 5306-00-144-3666 - 3 ea
AN 3-32, FSN 5306-00-144-3667 - 23 ea
AN 3-33, FSN 5306-00-144-3668 - 3 ea
AN 3-34, FSN 5306-00-144-3669 - 1 ea
AN 3-35, FSN 5306-00-144-3670 - 12 ea
AN 3-40, FSN 5306-00-144-3673 - 8 ea

Washer, Steel, CAD No. 10

AN 960-10L, FSN 5310-00-167-0834 - 150 ea
AN 960-10, FSN 5310-00-167-0818 - 150 ea

Fiberglass taper pins